Grasp

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In seeking a short, sharp title for this essay, I vacillated between *grip* and *grasp*. When consulting Dr. Dorland's *Dictionary*, I was surprised to find the primary definition of grip was "French, grippe influenza." I therefore chose grasp, even though it does not appear in the good doctor's dictionary.

Despite the fact that the skeletal and muscular elements of the human hand are very nearly matched in many species, praise of our own human hand and its abilities is a very natural human weakness. In fact, the history of human civilization is replete with special studies of the hand. Galen (AD 129–199) devoted a large part of his *De Usu Partium* to the anatomy and physiology of the hand. Throughout the centuries, mystical properties have been imputed to the hand, and many gullible people have had their lives directed by the pronouncements of palmists.

Sir Charles Bell, in the first chapter of his fascinating fourth Bridgewater treatise—written >160 years ago—asserted that there is in the hand "a universal plan extending through all animated nature and which has prevailed in the earliest condition of the world, and that on the most comprehensive study of those subjects, we everywhere behold prospective design" (1).

In the second half of the 20th century, the writings of John R. Napier, an anthropologist-physician, are preeminent. His book *Hands*, first published in 1980 and now in its third edition, is *the* book to be recommended to nonspecialists interested in the evolutionary, functional, and behavioral aspects of the hand.

The best comparison and differentiation between nonhuman primates' hands and our own lies in the manner in which the hand is able to grasp something. The anthropoids' grip is strong and secure, but its range of function will remain small because of its less developed thumb. It is at best a "power grip," but it does not have the "precision grip" of the human hand, which has achieved excellent refinement in prehensility.

This, however, does not mean that the human hand has lost the more primitive ability of the power grip or any other movement of the primate foot-hand. Essentially, the anatomical structure of our hand is no different from that in a gorilla, with the exception of the opposability of the thumb. What has changed is that over time, a strong hand remained strong but acquired more intricate capabilities. Monkeys are basically quadrupedal; man is fully bipedal. Our upright walk makes all the difference. During the last century, many discoveries have led to the understanding of the origins of our hands and their capabilities.

ORIGINS

In 1650, Archbishop James Ussher determined to his satisfaction that the earth was created on the evening of October 22, 4004 BC. John Lightfoot, another divine, claimed that the correct time was 9:00 AM on October 26, 4004 BC. We now know they were off by many millions of years.

Precursors of the skeleton of our human hand can be traced back at least 370 million years to the pectoral fin of an extinct fish. The basic pentadactyl (5-digit) hand is found in skeletons of mammal-like reptiles that lived 200 million years ago. Sixty-five million years ago, the basic hand skeleton became a fixed mammalian characteristic. Around 25 million years ago, the apes living in the forests began to develop more mobile forelimbs and hands with longer, stronger fingers. Their thumb was short and lacked both long flexor and extensor tendons, and the fingers and nails were curved to aid in grasping tree limbs. Our first unequivocal ape ancestor lived 19 million years ago. Named *Proconsulitous*, it was about the size of a fox terrier and had fingers that were flat nailed and had a pseudo opposable thumb. Some apes developed a knuckle-walking gait similar to that of modern chimpanzees.

About 5 million years ago, future man split off from the apes, and between 3 and 4 million years ago "Lucy" developed. Properly named *Australopithecus afarensis*, her given name was derived from the Beatles' song "Lucy in the Sky with Diamonds," which was popular at the time her bones were discovered (2). Lucy was 3½' tall with arms longer than modern man and small, strong hands. Thus, around 3 million years ago we have the first evidence of a true bipedal hominid. It was another million years before tool use developed. There is now evidence that modern man has existed for at least 100,000 years and that he used tools made of stone, bone, horn, and wood. The science of molecular genetics has now vindicated Darwinism and, no doubt to the discomfort of some, has shown that almost 99% of our DNA is identical to that of the chimpanzee.

STRUCTURE AND FUNCTION

Skin is the most ancient sense organ of our body, and the skin of our hand is highly specialized to provide detailed sensory feed-

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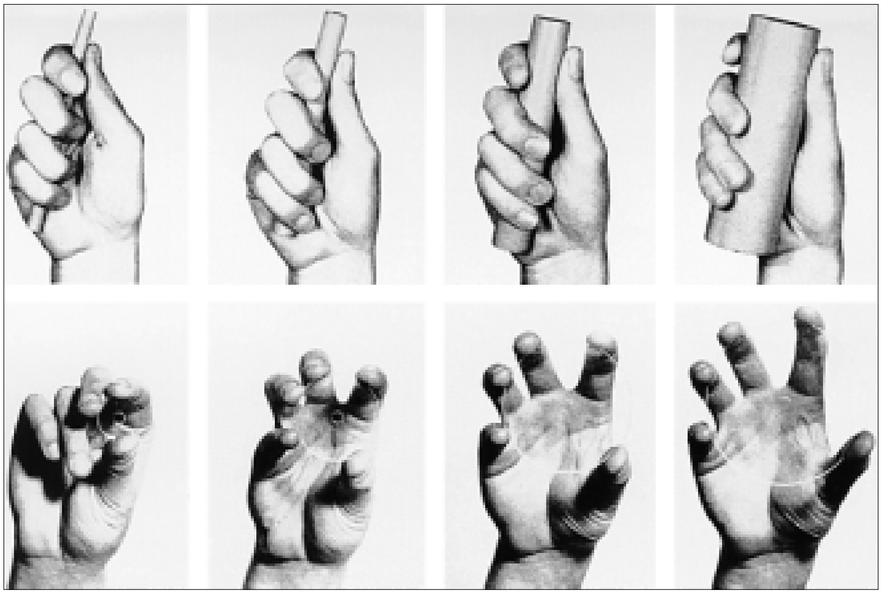

Figure 1. Power grasp and precision grip. In grasp the object is pulled into the hand and rests on the thenar muscles. In precise actions the object is usually held away from the palm. Reprinted with permission from Napier JR. The prehensile movements of the human hand. *J Bone Joint Surg* 1956;38B:902–913.

back. Since mobility is concentrated toward the concavity of the palm, its nerve endings are far more numerous than are those on the dorsum. The most sensitive area is the central whorl or loop of the fingertips in which the threshold of touch is 2 g per mm^2. In contrast, the threshold is 33 g in the forearm and 26 g in the abdomen. This acute sensibility is explained by the presence of some 2400 to 2500 nerve endings in each 9-mm^2 area. Deeper sensibility in the fingers is supplied by a rich nerve plexus in which, among many nerve endings, are >800 of the estimated 2000 Pacinian corpuscles in the whole body.

On the dorsal extensor surface the skin of our hand is thin and loose, and on the palmar aspect it is thicker and tethered to the deep fascia by strands passing from the flexion creases. The palmar creases or "skin joints" do not correspond to the underlying bony joints but anchor the skin during grasp. Subsidiary creases on the fingers fold up the skin that balloons up when the fingers are flexed (see your own proximal interphalangeal joint).

These creases are not the result of use; they are present in the newborn baby's hands. Many other minor creases are present, and throughout the palmar aspect papillary ridges carry sweat glands which open along the ridge crests. The sweat provides an adhesive quality, preventing slippage of tools, and enhances the appreciation of pain and touch. The pattern of these ridges is unique and unchanging and is established by the 12th week of intrauterine life.

John Napier has written, "I suppose we all have our heroes. I have three—Hunter, Bell, and Darwin. John Hunter turned our attention from the structure of the hand to its function; Bell related the function of the hand to the environment; and Darwin demonstrated that the environment, by the process of natural selection, gave birth to structure" (3).

I would add a fourth hero, a general practitioner from Boulogne, France, Gulliaume Duchenne, who in his book *Physiology of Motion* published in 1855 made the forthright statement, "The hand as understood physiologically is nothing but an unsightly paw more awkward than useful." Despite this stricture, he comprehensively described the normal and abnormal motions of the hand. His great contribution was to use electrical stimulation to demonstrate the complexity of motion during grasp, pointing out that many muscles participate, some as direct motors, some as moderators, some as restrainers, and some as antagonists.

THE MUSCLES

Mechanically, the grasping hand is a 2-sided chuck with the mobile thumb on 1 side and the fingers on the other. This chuck provides our refined and powerful pinch and grasp mechanism. The fingers on the opposite side of the grasping chuck are each capable of independent action. Opposing the powerful flexor mechanism is the weak extensor apparatus, whose major function is to open the fist and lift the digits against gravity.

The power of grasp is derived from 2 groups of muscles: the extrinsic and the intrinsic. The extrinsic muscles in the forearm provide the major power of the hand. The intrinsic muscles within the hand are of fundamental importance, since they are largely responsible for the refinement and delicate control of digital movements. These small muscles achieve their control by modifying and moderating the actions of the long extrinsic muscles.

Opening the hand and then closing it around an object is a very complicated motion. Simultaneous contraction to varying degrees of the 35 muscles in the forearm and hand will create a grasping motion. If you are among the 20% of humans who do not have a palmaris longus muscle, then you have only 34 muscles working for you. Unfortunately, you lack a muscle that can be used in reconstructive surgery. Its absence does not hinder you. To test if you own one, press your thumb tip against your little fingertip and flex your wrist against resistance. The palmaris tendon will stand out under the skin in the middle of the wrist crease.

Three phases operate when grasping large objects. In the first the hand opens widely from action of both the long extensors and the intrinsics. Then the object is surrounded largely by intrinsic action. Closure and firm grasp result from the strong action of the extrinsic flexors and the intrinsics of both the thumb and fingers. Finally, slight extension of the wrist tightens the grip even more.

The great variability in the postures of grasp would seem to exclude easy classification. But in 1956 Napier in his classic paper "The prehensile movements of the human hand" showed that all forms of grasp can be grouped as either power or precision grasp, with a third category combining elements of both *(Figure 1)* (4).

Power grip is thought to have developed early in humans and consists of a prehensile movement in which the object is grasped by the fingers and pressed against the buttress of the thumb and its intrinsic muscles. This is a powerful movement with little skill involved. Precision grip is thought to be the most recent adap-

Figure 2. Intrinsic minus hand. The metacarpophalangeal joints are hyperextended, and the interphalangeal joints are flexed. Note that the tip of the long finger is shortened and rounded; absorption of the terminal phalanx has already started.

tation of the evolving human hand. It is an accurate prehensile action in which the object may be held away from the palm between thumb and fingertips. Some activities require features of both grips, as in tying 2 pieces of string together; the power fingers (ring and small) hold the string, and the precision digits (thumb, index, and long) do the precise activity of creating the knot. The so-called hook grip, while of great use to the apes suspended in trees, is only of use in humans when carrying suitcases.

Formerly 3 clinical models could be used for the study of grasp. Nowadays, with the conquest of poliomyelitis, only the rheumatoid hand and the leprosy hand are available. Practically every biomechanical imbalance that afflicts the hand occurs in one or the other of these 2 diseases.

Studies show that a power grasp of about 5 lbs per in^2 will keep a hammer handle from slipping out of the palm. However, if skin sensory feedback is impaired, then strength has to be increased to provide deeper sensory feedback. In the extreme case of the "blind" hand of Hansen's disease (leprosy), the neurological changes cause a collapsed posture of grasp and a concentration of force at the tips of the digits. The normal palmar surface grip area in an adult is about 10 in^2. The intrinsic minus posture of leprosy allows only fingertip grip, concentrating the force of grip into an area of about 1 in^2 *(Figure 2)*. The final resultant force in this small area is huge and reaches about 250 lbs per in^2:

5 lbs per in^2	$\times$	5	$\times$	10 in^2	$=$	250 lbs per in^2
normal pressure		increase for lack of sensibility		adjustment in surface area*		actual pressure during grasp

*Pressure usually applied in an area of 10 in^2 is now in an area of 1 in^2.

The high grip pressure causes persistent microfractures, bone absorption, and ultimately disappearance of the digits *(Figure 3)*.

Just as in leprosy, in which the internal forces of grasp destroy the skeleton, so in rheumatoid disease the aberrant forces produced by soft tissue disease disarray the normal forces of grasp. The more the patient increases the force of grasp, the greater the self-destruction of the normal postures of grasp.

Many factors influence the strength of grasp. Studies show that grip strength is greatest around 3:00 PM each day (5). Actual strength will vary with age and sex. A strong grasp reflex is present at birth. A baby begins to develop control of strength around the age of 2 as appreciation of the friction between skin

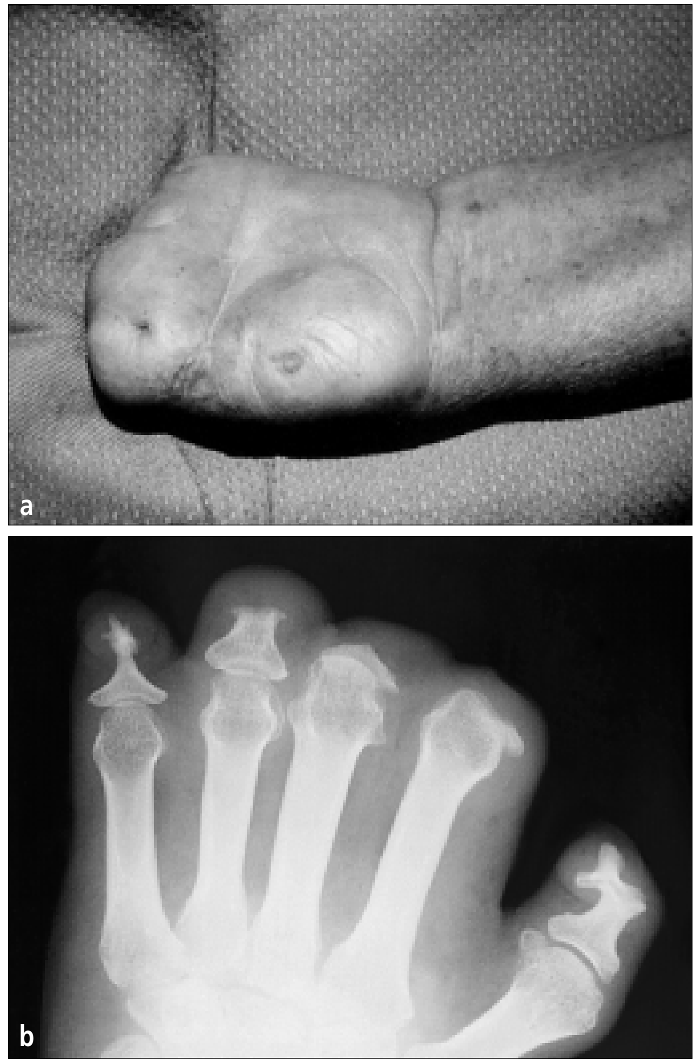

Figure 3. Hansen's disease. **(a)** Late stage. The fingers have absorbed and only a flipper of a hand is left. **(b)** X-ray of late stage.

and object develops. Progress is slow and early on is compensated for by excessive use of force (6). Gloves produce a significant drop in grip strength. Ordinary working gloves cause a reduction of 14% to 28%, while the inflated gloves of the astronaut produce a 37% reduction in strength.

Proper grasp is dependent upon appropriate lengths of the constituent bones of the palm and digits. These lengths are in fact proportionally related and determine the form and shape of grasp. The different lengths of the fingers disappear when a sphere is grasped; the fingers abduct and rotate and the tips line up. When grasping a cylinder, there is a normal inclination of palmar grasp, a fact unfortunately not well known to the manufacturers of crutches, who still copy the ancient Roman model. If only they would slope the handle, it would not force the wrist into a painful end position *(Figure 4)*.

Our work has shown that regardless of wrist position, the percentage of total grasp force allocated to each finger is constant. The long finger shows the greatest amount of force, with approximately 33% of the total force. The index and ring fingers have about 25% each, and the small finger has approximately 16% of the total force (7).

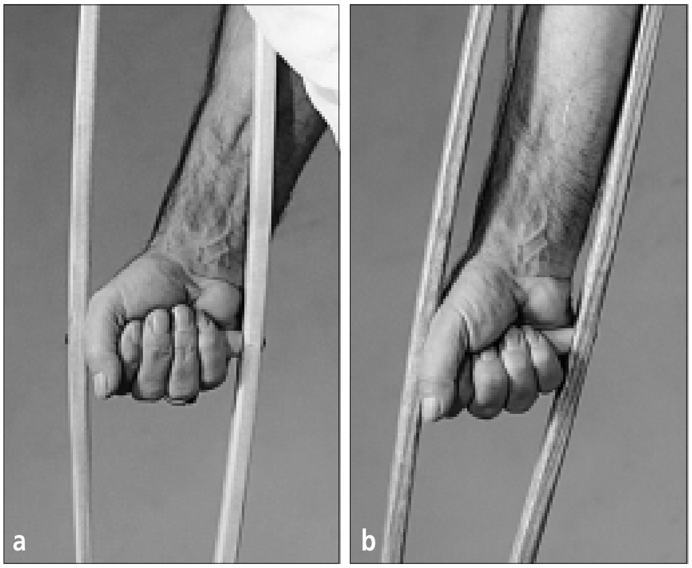

Figure 4. The inclination of grasp. **(a)** Horizontal crutch handles force the wrist into an uncomfortable position. **(b)** With a sloped handle, the wrist is comfortably in line with the forearm. Reproduced with permission from *Geriatrics* 1960;15:733–745. Copyright by Advantstar Communications Inc. Advantstar Communications Inc. retains all rights to this article.

The type of grip used in any given activity is a function of purposeful action and is not dependent on the shape or size of the object grasped. Humans have now moved beyond using rocks and fallen branches as tools, and as Benjamin Franklin said, "The tool user has become a tool maker." Unfortunately, the current—cosmetically attractive—tendency to make digital profiles on tool handles severely restricts the range of hand sizes that can comfortably grasp the tool. The size and shape of tool handles should be such that the digital joints are near mid-flexion so that tool retention is high and the muscles are only partially stretched. Recent "ergonomic" designs show a great improvement. In surgery a round handle for the scalpel blade is wonderful; one can readily adjust the blade angle. The regular thin flat handle was probably invented by the Romans!

RESTORATION

In the latter part of World War II the American army set up 10 hospitals in the USA for the exclusive treatment of upper-limb injuries. Thirty-five young surgeons were trained in reconstructive hand surgery, and what is now a worldwide specialty was born.

The basic objective of the specialty is the restoration of skilled function to a hand disabled by congenital defects, trauma, or disease. The fundamental functions are that of precision grip or power grasp. Two factors are paramount in their restoration: a thumb that moves or can be stabilized and fingers that flex. In massive injury, particularly when it is bilateral, restoration of both power and precision grips to both hands may not be possible. It may well be that the remaining serviceable parts will restore precision grip to the nondominant hand and power grip to the remnants of the dominant side. This is far better than attempting to restore both functions to both hands using inadequate resources.

Destruction of the individual nerve supply within the forearm or hand, such as the median, ulna, or radial nerves, produces recognizable patterns of function loss. Standard plans of effective tendon transfers have evolved, and such surgery has now become routine. When >1 nerve is involved, functional restoration becomes more difficult and the results are less efficient. Precision activities are lost first and, depending on the extent of damage, only grossly controlled motions may be possible.

During the days of poliomyelitis, paralysis of thumb opposition was a frequent occurrence. Since this is a fundamental component of grasp, a great many operations have been suggested for its restoration. Unfortunately, many of these procedures failed to appreciate that the thumb is, in effect, a post projecting into space with a very mobile joint at its base. Accordingly, a thumb has to be supplied with at least 3 "guy ropes" distributed around its circumference to hold the thumb erect. The flexor pollicis longus, the extensor pollicis longus, and the abductor pollicis longus usually supply the necessary stability. Once stability is achieved, then a fourth muscle can be transferred to move the thumb into opposition.

The prime mover into opposition is usually made from the flexor superficialis of the ring finger. Its removal does not interfere with grip in the presence of an intact flexor profundus tendon. A pulley is made in the region of the pisiform bone, and the transfer is attached near the metacarpophalangeal joint. After 3 weeks of immobilization, the transfer can be taught to produce opposition in an astonishingly short time—usually about 10 minutes.

Since the conquest of poliomyelitis, this operation is still in use to provide opposition when its absence is caused by trauma or neurological disease. For patients with progressive neurological conditions, a positive "can-do" attitude will provide, through an operation lasting an hour to an hour and a half, significant temporary improvement in grasp. Some of these individuals have been among my most grateful patients, even though they know the result cannot be permanent.

When trauma has amputated the thumb or one is born with an absent thumb, the hand is reduced to a virtual hook and no form of opposition is possible. Indeed, Napier has written, "Without the thumb the hand is put back 60 million years in evolutionary terms to the stage when the thumb had no independent movement and was just another digit" (8). Such a state is unacceptable, and a thumb has to be provided. The best substitution is one of the fingers, and technically it is possible to move any of the fingers across onto the base of the destroyed thumb. However, the use of any finger other than the index produces an indifferent thumb and is best regarded as a surgical triumph and a functional disaster.

The translation of an index finger onto a thumb stump is a relatively easy procedure and gives a highly functional result (*Figure 5*). The cerebral cortex readily adjusts to its new responsibilities, but at first the new thumb is often inadvertently used by its owner as a pointer. This patient's insurance company kept writing to me demanding to know whether he should be compensated for loss of thumb or loss of index finger. My reply? Both!

In infants born with 4 fingers but no thumb, a thumb can be readily made from the index finger. However, the conversion of an index finger to a thumb necessitates some shortening since in the normal hand the tip of the thumb usually reaches just proximal to the line of the proximal interphalangeal joint of the index finger. This shortening is accomplished by removal of most

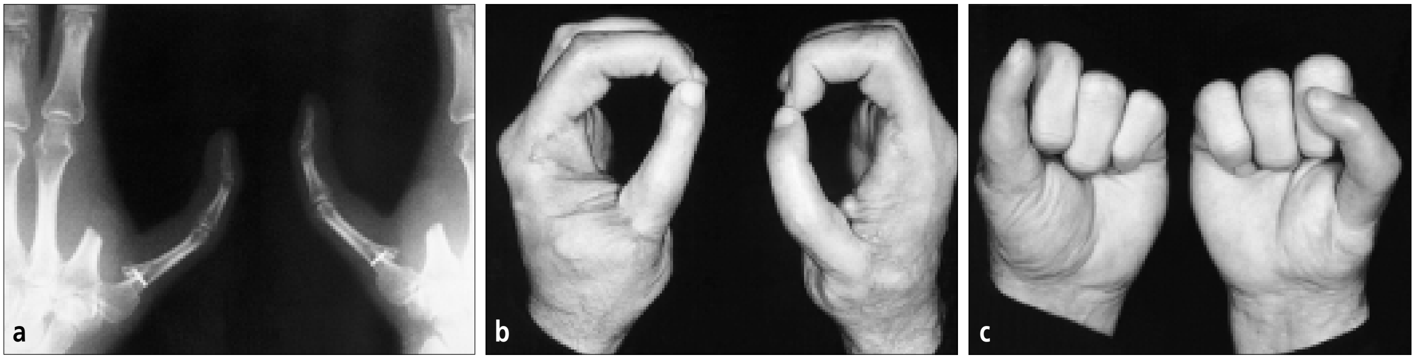

Figure 5. An electrical accident burned off both thumbs in this adult man. Parts **a, b,** and **c** show 3 different views of the transposition of both index fingers, which restored grasp. The man returned to work on power lines.

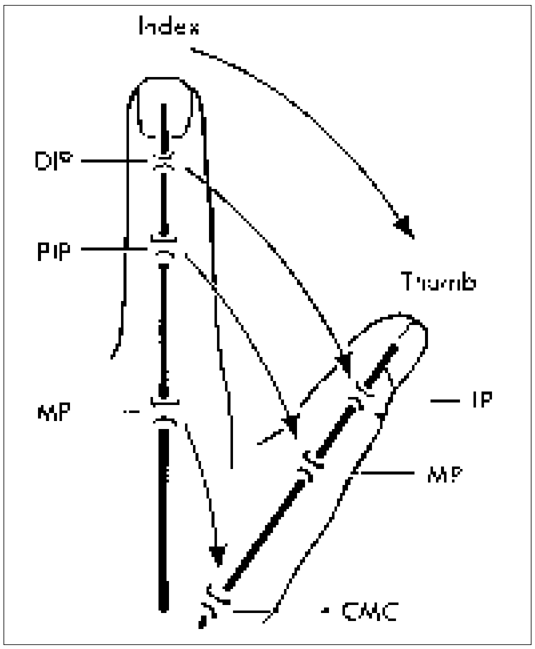

Figure 6. Pollicization—joint distribution. The 3 joints of the index finger become the 3 joints of the thumb, but the index metacarpophalangeal (MP) joint becomes the carpometacarpal (CMC) joint of the thumb. Reprinted with permission from Flatt AE. *The Care of Congenital Hand Anomalies,* 2nd ed. St. Louis: Quality Medical Publishing, 1994:104.

Figure 7. Pollicization. In the early development of this operation, the growth center in the index metacarpal head was not destroyed. It continued to grow, producing a grotesque digit. Reprinted with permission from Buck-Gramcko D. Pollicization of the index figure. *J Bone Joint Surg* 1971;53A:1605–1617.

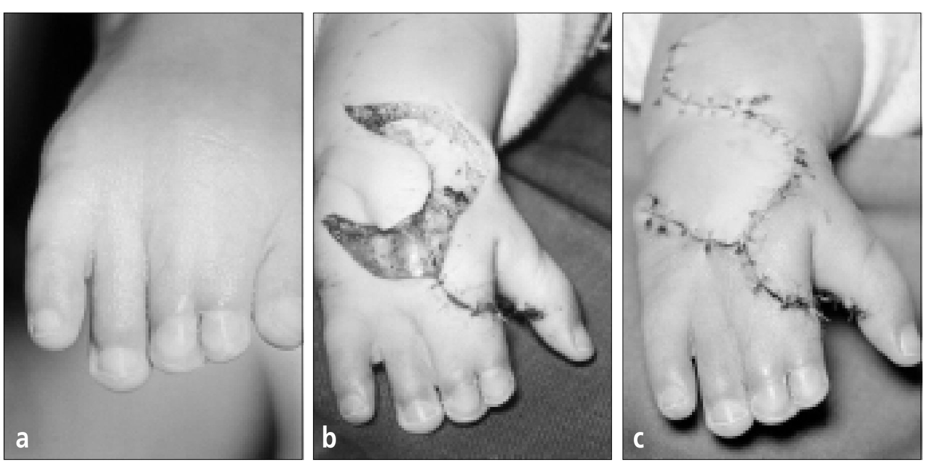

Figure 8. (a) Adducted thumb. **(b, c)** By judicious use of rotating skin flaps, the thumb can be liberated and clothed with full-thickness skin. Vascular supply and cutaneous nerves are carried in the flaps. Reprinted with permission from Flatt AE, Wood VE. Multiple dorsal rotation flaps from the hand for thumb web contractures. *Plast Reconstruct Surg* 1970;45:258–262.

Figure 9. Quadriplegia. The ability of limited grasp can be restored with only 1 functioning muscle in the forearm. **(a)** The thumb is shortened and stabilized. **(b)** A variety of functions are supplied by the operation. Reprinted with permission from Flatt AE. Indications for shortening of the thumb. *J Bone Joint Surg* 1964;46A:1534–1539.

of the metacarpal shaft, but the head is retained since it will become a new trapezium *(Figure 6)*. The key to this shortening is destruction of the growth plate of the metacarpal head. This arrests longitudinal growth at the base of the new thumb and prevents the development of the grotesque thumbs made by earlier methods *(Figure 7)*. This operation should be done early so that the child uses the thumb normally and is never aware of its original absence. I usually do it at about 6 months of age and believe it should always be done before the first birthday.

Infants born with webbed hands in which their thumb is tightly adducted to the index finger can have full restoration of grasp by liberation of their thumb. Three rotation flaps can be moved down the forearm to completely cover the thumb with sensate skin, and no skin grafting is necessary *(Figure 8)*.

Even patients with high spinal cord lesions, which leave only 1 forearm muscle under voluntary control, can be given significant improvement of function. For the patient illustrated in *Figure* 9, a 2-stage operation was used. The first procedure anchored the finger flexor tendons to the radius with the lengths arranged so that there was a normal cadence of flexion with the least in the index and the most in the small finger. When the wrist was extended by the sole working muscle (extensor carpi radialis longus), the fingers would close in grasp. However, the paralyzed thumb intruded into the palm, blocking grasp. The second-stage operation shortened the thumb by removing the proximal phalanx and fusing the distal phalanx to the metacarpal head. The phalanx was used as a bone graft, fixing the thumb in abduction and radial deviation from the hand. This provided a variety of useful functions for a previously flaccid hand. I first published this operation in 1964 and have used it ever since for patients with high neurological loss and for spastic patients. Surprisingly, these hands do not appear grotesque, and most lay people do not realize the thumb has been shortened.

The field of hand surgery has grown exponentially since World War II. The original 35 military hand surgeons founded the American Society for Surgery of the Hand in Chicago on January 20, 1946. Today there are 1213 active members of this society dedicated to the improvement of and education in restoration of functions to the hand. A major effort has been the training for the next generation of surgeons; I have trained 50 hand surgeons from 11 different countries and many of my colleagues have similar records, so that now 49 countries have trained hand surgeons who are members of the International Federation of Hand Surgery.

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